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AN INTEGRATED SYSTEM FOR COLLECTING AND ANALYZING ENVIRONMENTAL TEST DATA

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SUMMARY

The simultaneous evaluation of several spacecraft in simulated space environments results in a large volume of data relating to the performance of the spacecraft and to the generation and measurement of the environment. The timely and effective collection, processing, and reduction of these data can only be achieved by means of an automatic data-handling system. This system must be versatile, accurate, and reliable. Such a data system has been designed and installed at Goddard Space Flight Center. It organizes and reduces the data generated, both as an aid to effective control of test operations and for optimum analysis and storage of the test data. The experimenters and test personnel are released from routine data gathering and reduction and permitted to concentrate on data analysis and interpretation.

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INTRODUCTION

Goddard Space Flight Center has a facility for testing and evaluating the performance of instrumented satellites and probes in simulated space environments (Figure 1). This Spacecraft Test Facility includes thermal-vacuum chambers, temperature-humidity chambers, optical test chambers, vibration test systems, centrifuges, moment of inertia machines, spin and balance equipment, and tension-compression test equipment. Data must be collected and analyzed for use in controlling the spacecraft environment and the stimuli applied to satellite sensors, for determining the outputs of the sensors through the satellite telemetry systems, and for observing the internal functioning of a satellite at critical system points.

During the planning for this facility, it was decided that great advantages in speed and convenience could be realized by providing a largely automated data collection system for the entire facility. The system as installed consists of portable data collection modules, a permanent transmission cable system, a section known as Data Central (Figure 2) where data are assembled, recorded, and analyzed, and an Operations Center for monitoring spacecraft tests.

The capability of the data system can best be visualized by considering its application in the test of an observatory. This is a satellite which may contain a large number of separate experiments—instrument packages designed to study separate physical parameters in the orbital environment. These experiments use a common vehicle, power supply, and transmission system, but

*Booz-Allen Applied Research, Inc., assisted Goddard Space Flight Center in determining the system requirements, writing the performance specifications, and monitoring the design, fabrication, installation, and shakedown of the system. Epsco, Inc., designed, constructed, and installed the hardware, using some proprietary components from other manufacturers.

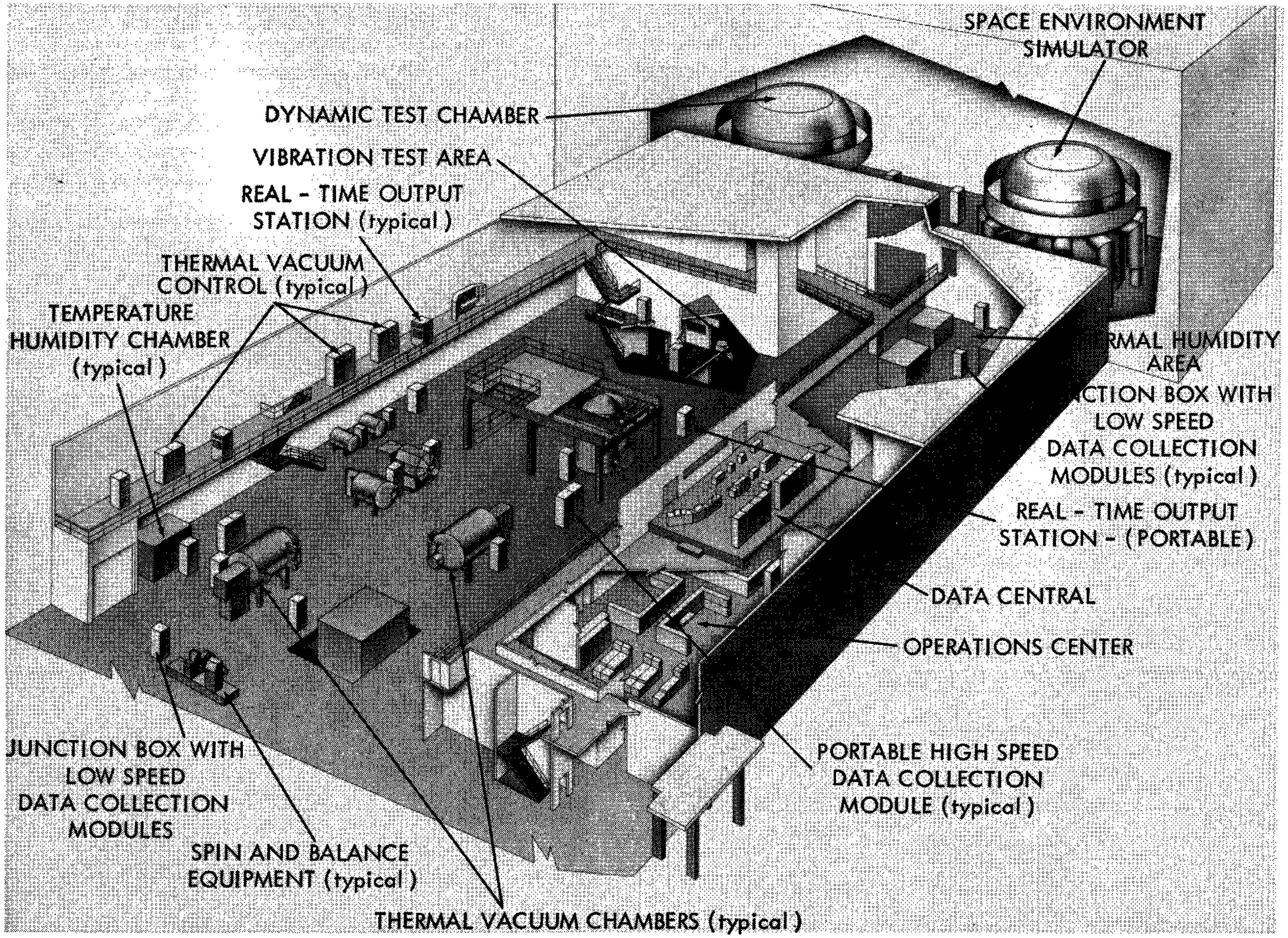

Figure 1—Spacecraft Test Facility, buildings 7 and 10, Goddard Space Flight Center.

Figure 2—Data Central.

each experiment may be designed and fabricated by a separate group. Various government agencies, universities, and industrial laboratories may build experiments for a single observatory.

When such a satellite is undergoing a test in a simulated space environment, literally hundreds of different data channels are needed to acquire and organize the information required in evaluating the observatory's performance. Data must be collected and displayed for the use of the experimenter, those who control the environments, and those who evaluate the overall performance of the observatory. Each of these requirements may have its own time frame and format. The complexity of the design requirements for this data system may be appreciated by considering that three major tests and a number of simpler tests may be conducted in the facility simultaneously.

SYSTEM CHARACTERISTICS

The principal characteristics of the system are its versatility, its accuracy, and the careful control which is maintained over the data collected.

Data can be collected from approximately 3500 different points, selected from more than 10,000 points distributed in some 23 different physical locations in the 60,000 ft^2 building complex. Sampling rates range from the order of a few samples per hour to 15,000 samples per second. A wide variety of signal conditioning is possible, including thermal referencing, bridge balancing, amplification, and attenuation. Setups and changes can be made conveniently and quickly without interrupting other tests.

The system in operation handles data well within the specified span accuracy of 0.25 percent. This accuracy was achieved by careful engineering of the entire system, including the long runs of shielded analog cables. It also required an engineered instrument grounding system for the building, and a rigidly enforced shielding and grounding discipline. Anything short of the most meticulous care in this regard could cause extreme signal degradation.

The unifying element of the system is the flexibly assigned but rigorously controlled format, into which the overall system data are assembled. This format contains 7500 eleven-bit-plus-sign words per second. The format is enforced by the master system clock, which provides the timing for all sampling, conversion, and assembly in the system except for telemetered data which is asynchronously controlled by clocks on the satellites. The result is a stream of data, each item precisely identified and placed in time. A space in this format is reserved for each data channel, whether or not it is presently in use.

The flexibility of assignment is achieved by using a removable patch panel at the test site and control switches in Data Central. The patch panel permits the pretest assignment of individual channels to individual format spaces, including supercommutation and subcommutation. The switches in Data Central select the block location of each of the high speed data collection modules in the data format. These switches can supercommutate the collection modules within the format, thereby increasing the sampling rates by a factor of 2, 5, or 10 over the rates selected by the patch panel. An on-line computer, under program control, selects data words from the format for reduction and display.

The philosophy of system operation is that the outputs are to be kept to a minimum by planning in advance the information to be delivered to each output station. This precludes tying up the system with masses of raw output, and permits the computer to produce sophisticated results, eliminating the need for further manual reduction. Thus, technical personnel can devote their efforts to data analysis and interpretation, rather than to routine data collection and manual reduction.

DATA COLLECTION

Low Speed Data

Slowly varying parameters such as temperatures, pressures, and relatively stable voltage and current levels are measured by a low speed subsystem. This subsystem takes 25 samples per second and has a nominal capacity of 2500 separate data channels. The data from this subsystem are handled in two parallel ways. First, all the data are recorded on a low speed magnetic tape for later off-line processing. Second, the low speed data are intermingled with the high speed data in the overall system data format; then they are sent to an on-line computer which provides instantaneous readings in engineering units for the direct monitoring of facilities and experiments.

High Speed Data

Electrical measurements can be made at a system rate of 7500 samples per second on a maximum of 1000 separate channels. The measurements which can be made include:

1. Current and voltage levels on satellite power circuits.
2. Radio frequency power.
3. Voltages, currents, and transducer outputs in several ranges from ±8 millivolts to ±320 volts full-scale, with a system bandpass of 500 cps.

The measurements taken by this subsystem, with the low speed data intermingled, are handled in two parallel modes. In the normal mode, a burst of 6 seconds of data is recorded on magnetic tape with a 5 minute interval between bursts. Simultaneously, all the data are recorded in "ping-pong" fashion on two tape transports operating alternately. Each transport records 5 minutes of data and then rewinds and waits while the other transport records for 5 minutes. If no emergency or malfunction occurs, the data are erased through re-use of the tape. If an emergency is detected, all the data recorded during the previous 10 minutes can be analyzed. In addition to these two recording modes, a limited amount of real-time data processing by the on-line computer is possible.

Extra-High-Speed Data

To handle rapidly fluctuating data, a special arrangement can be made by which 100 channels of electrical measurements of the same types as those described above can be taken at a system rate of 15,000 samples per second. These measurements are recorded on a high speed tape transport holding approximately 3-1/2 minutes of data. The data are handled in parallel with but entirely separate from the data within the overall system format.

Data Recorded Outside the System

Data can be introduced into the system which have been recorded elsewhere in the form of punched tape, punched cards, or magnetic tape, either digital or analog. These data can then be converted to other forms or analyzed and compared with data collected in the test facility.

Telemetered Data

Data coded and multiplexed in the telemetry systems of satellites being tested within the facility can be introduced into the computer subsystem and recorded on tape for future processing at a maximum aggregate data rate of 14,000 twelve-bit words per second. When real-time processing of these data is desired, a second (off-line) computer is brought on-line through the central memory.

Running-Time Data

The running times of up to 230 major items of equipment within the facility are recorded by the running-time subsystem. This subsystem records on punched paper tape the clock time, the channel designation, and the on or off status of each device. Fifty of the samples are taken once every minute and the remaining 180 devices once every 5 minutes. A reel of tape holds 4 days of data produced by this subsystem. Tape is removed biweekly and processed by the computer to produce updated machine-maintenance records and required maintenance reports.

DATA OUTPUTS

Real-time output stations (RTOS), either permanent or portable, are located at convenient spots near the test facilities (Figure 3). Under computer program control each station responds to an inquiry by displaying the reading of a designated channel on an in-line in-plane display, by plotting on a strip chart, or by printing out in engineering units the readings of a number of designated channels. Primarily provided for the display of environmental data, these stations can be programmed to display the output of any channel of the on-line system.

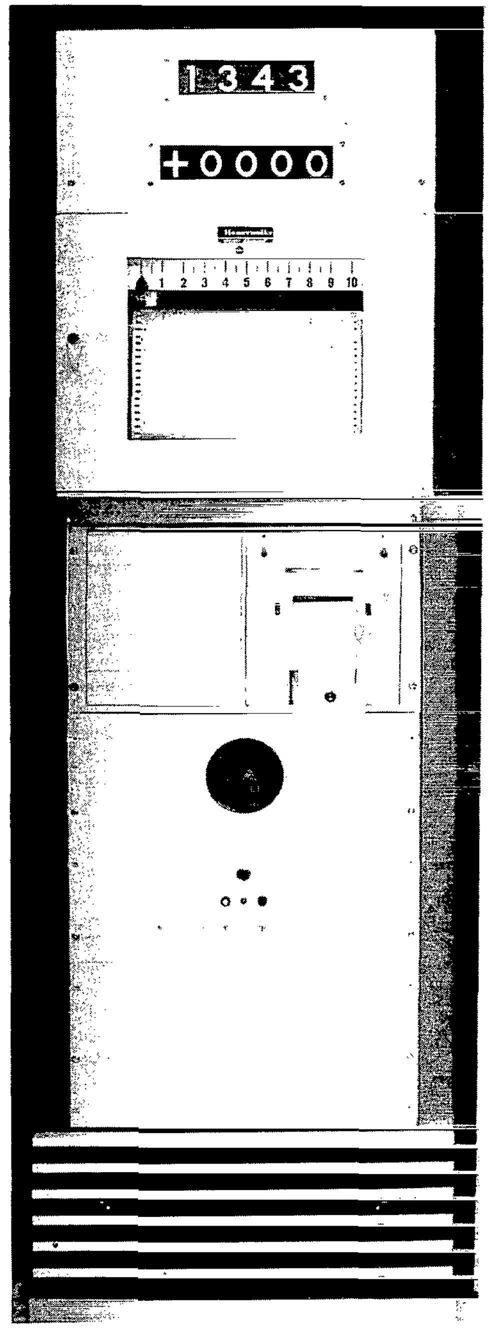

Figure 3—Real-time output station (RTOS).

Four cathode-ray bar-graph displays are located in the Operations Center. Each display shows the instantaneous readings on as many as 150 channels. A reading is displayed as a dot whose height above the base is proportional to the scaled reading on the designated channel. A negative voltage is designated by a dot below the horizontal base line. The horizontal scale can be expanded so that any 10 of the 150 channels may be examined closely. These displays are for the use of the experimenters and test personnel. They permit channel readings to be monitored in real time. Thus malfunctions or gradual changes in satellite system operating characteristics can be examined and the effect of sensor exercising can be observed. A malfunction indicated here is the normal reason for reviewing the data recorded on the "ping-pong" transports.

The satellite battery-power currents and voltages, also collected by the combined systems, are displayed on ammeters and voltmeters, and the RF power is displayed on wattmeters, on the collection modules located near the test stations.

Data recorded on tape by any part of the system, or stored in the computer memory in real time, are reduced and analyzed by the computer subsystem. The outputs are magnetic or punched tape, cards, typed reports, printouts, and X-Y plots. Considerable effort is devoted to ensure that these outputs are in final form for inclusion with test reports, or in convenient form for engineering or scientific interpretation.

SYSTEM CONFIGURATION AND DATA FLOW

The setup of the various components of the data-handling system and the flow of data from these components will now be discussed (Figure 4). The system configuration contains junction boxes and high speed and low speed data collection modules. The data are carried via various means into the Master Assembler and then to bar graph displays, tape transports, and the computer.

Junction Boxes

Junction boxes are permanently located at convenient spots near the major test facilities (Figure 4). They serve as termination points for the cables from the Operations Center and Data Central. These cables transmit data into Data Central and provide control connections for the experimenters. The junction boxes also house the low speed data collection modules (DCML's) described below, and provide quick-connect plugs for the high speed data collection modules (DCMH's), also described below.

Eleven test areas are served by major junction boxes, and the remaining twelve by minor junction boxes. A major junction box will accommodate an observatory, providing the system capability of connection to as many as six DCMH's and four DCML's, thus handling about 600 high speed and 200 low speed measurements simultaneously. In addition to the measurement channels, each major junction box contains the terminals of 60 analog control circuits for sensor exercising and 60 switching circuits for satellite control.

A minor junction box accommodates two DCMH's and two DCML's, providing about 200 high speed and 100 low speed measurement channels. In this case, 30 analog control circuits and 10 switching circuits are available.

Wires from the satellite and from the test facility enter the junction box from the top or bottom rear. Cables to the Operations Center and Data Central emerge through the bottom of the junction box and pass through the floor into the cable trays suspended from the ceiling below. The trays conduct them to a cable vault near the Operations Center for distribution.

High Speed and Low Speed Data Collection Modules

The high speed data collection modules (DCMH's, Figure 4) are mobile. They have the same width as two standard relay racks, are 78 inches high, and are equipped with wheels (Figure 5).

In practice, they are positioned next to the junction box to which a test is wired. Through quick-connect plugs the modules are connected to the setup wiring and to the building cables, both of which terminate in the junction box.

A DCMH can handle 100 channels of data. It provides power, voltage and current measurement and indication, transducer excitation power supplies, bridge completion units, amplification, and attenuation. Highly flexible provisions are made for channel selection, supercommutation, and subcommutation by means of a removable digital patch board which can be prewired in preparation for a test and quickly inserted in the DCMH. In the DCMH these various input signals are

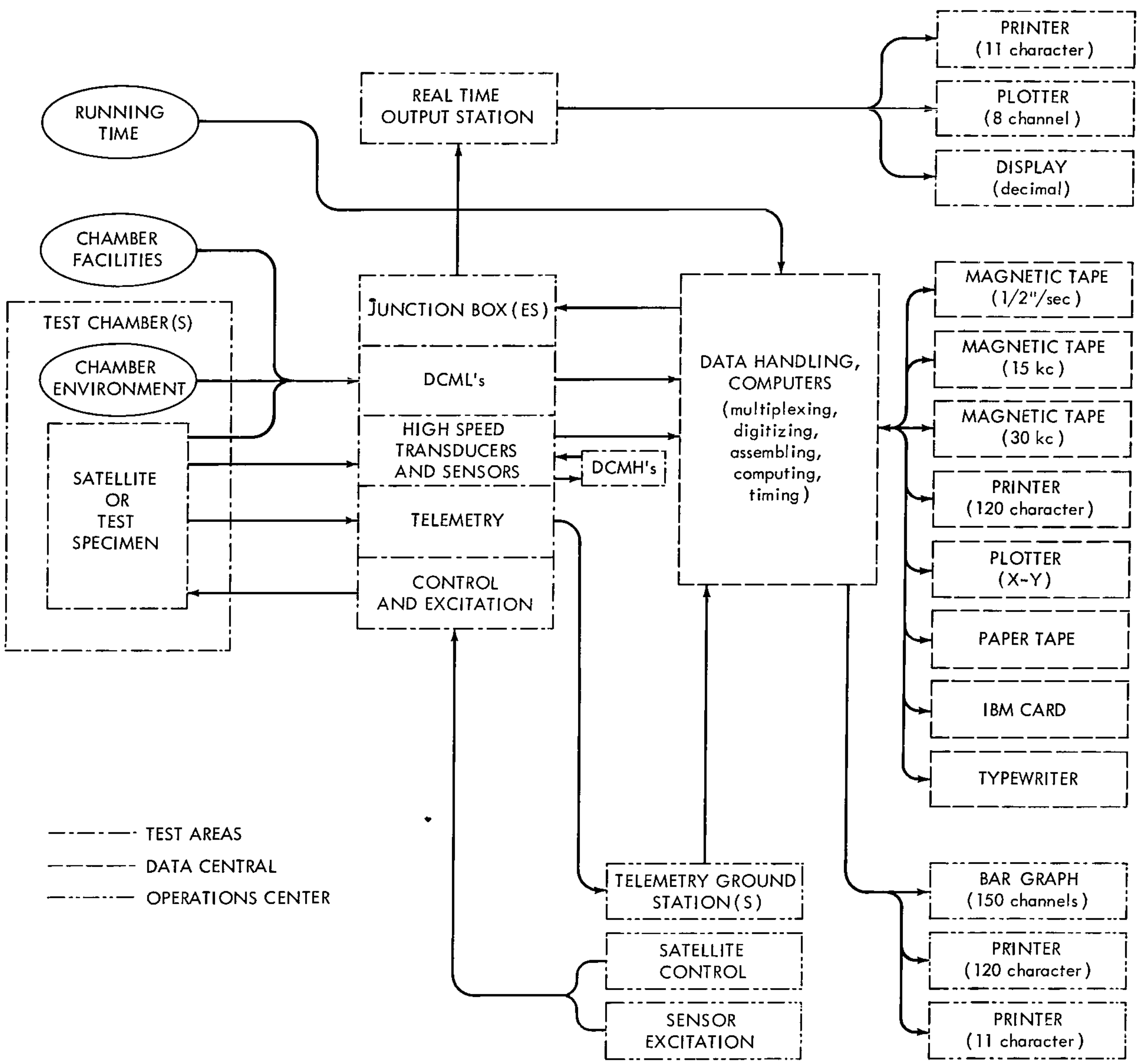

Figure 4—System configuration and data flow.

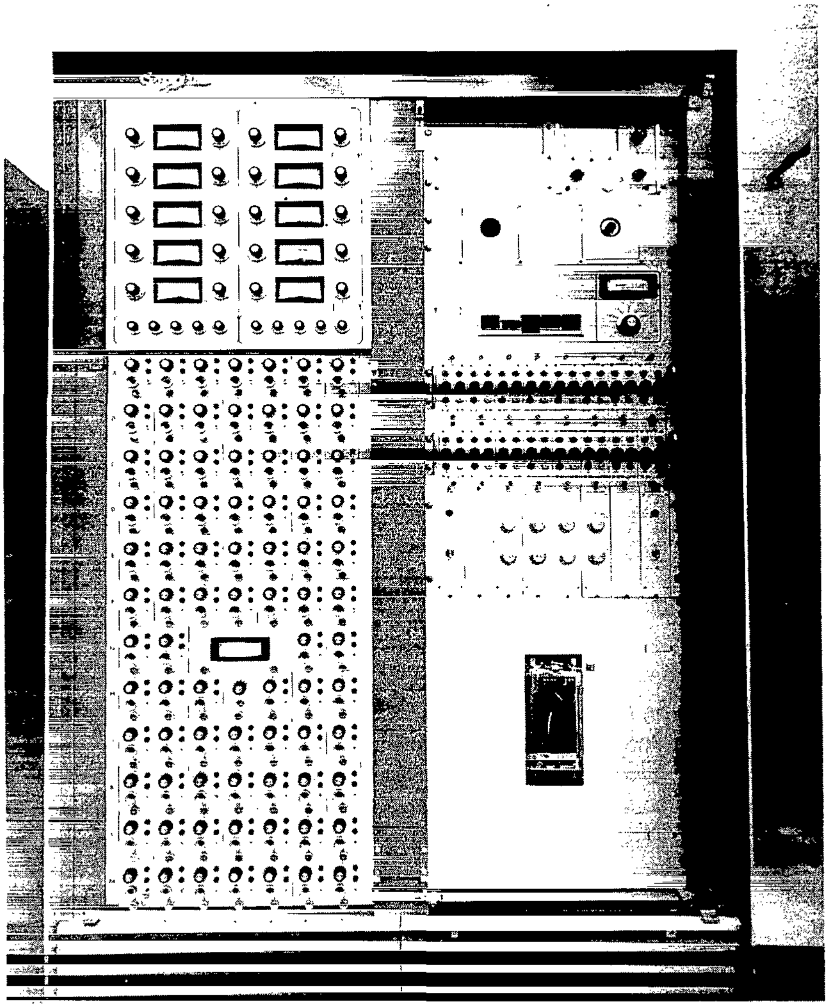

Figure 5—High speed data collection module (DCMH).

conditioned and amplified or attenuated as necessary to a full-scale value of ±5 volts. They are transmitted to Data Central through the permanent cabling as a pulsed analog signal at this level.

The low speed data collection modules (DCML's, Figure 4) are semiportable (Figure 6). When in use they are housed in junction boxes most convenient to the points of use. Each module is capable of receiving inputs from approximately 50 separate data pickups. A module provides thermocouple reference junctions, power supplies, and bridge completion and bridge balancing units for conditioning the data on these 50 channels. It receives the data through the wiring connecting it to the test facility or specimen, multiplexes it by means of a 50-point stepping switch, and sends it through the permanent building cables to the cable vault in the form of a pulsed, low-level analog signal of ±10 millivolts full-scale.

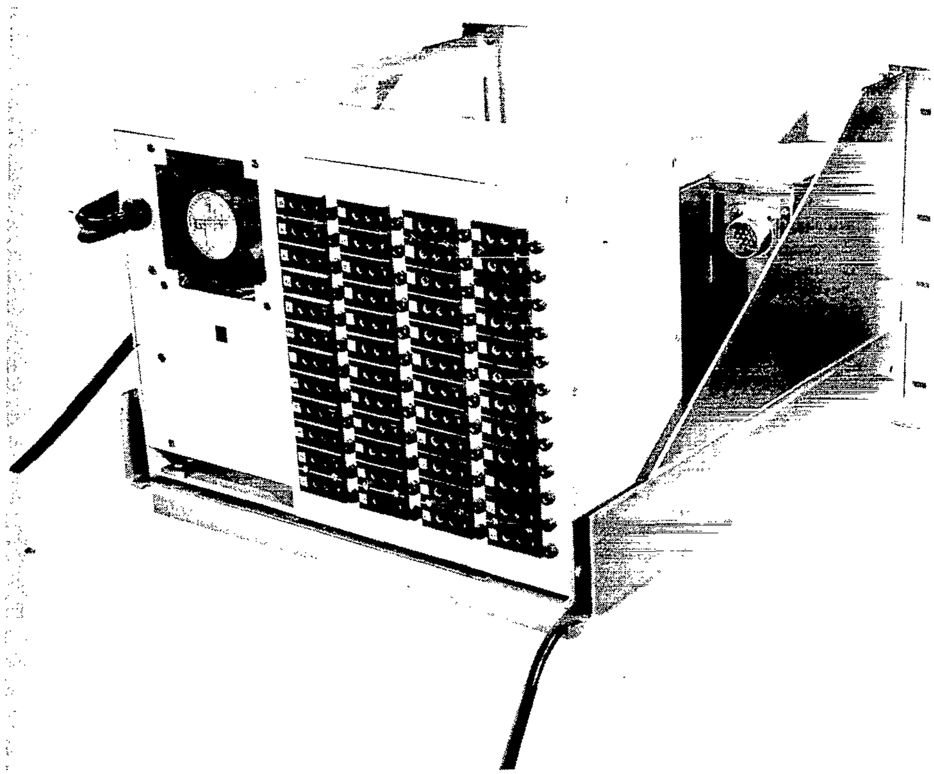

Figure 6—Low speed data collection module (DCML).

Data Transmission

The DCML data received through the permanent cables at the cable vault are multiplexed by a crossbar switch, amplified to a full-scale value of ±5 volts, and converted to digital form. The data are then driven through two parallel circuits. One circuit records them on the low speed data tape in Data Central; the other sends them to the Master Assembler in Data Central to be merged with the DCMH data.

In addition to this normal mode of operation, it is possible to switch the DCML data, in high-level pulsed analog form, into the Master Commutator of the high speed system. This emergency circuit takes care of a low speed converter failure.

The DCMH data are transmitted through the building cables and a patch panel to the Master Commutator in Data Central. After analog-to-digital conversion, they are sent to the Master Assembler. Here the DCMH data and DCML data are merged into the overall system data format.

Analog-to-Digital Conversion

The low speed system for DCML data, as noted above, has its own analog-to-digital converter. The high-speed data are converted by a converter which immediately follows the Master Commutator. The converters operate on a programmed successive approximation principle, converting each analog signal into digital form as an 11-binary-bit-plus-sign number. This gives a digital scale from -2000 to +2000 counts, corresponding to a transmitted analog signal of from -5 to +5 volts, and to full-scale negative and positive measurements at the respective data transducers. Digital output is limited to a maximum of ±2016 counts.

The converters operate up to 7500 conversions per second, being driven by the same clock that drives the commutators, to provide absolute synchronism. The digital outputs of each converter appear on 12 parallel lines; these outputs set the positions of 12 flip-flops in the Master Assembler.

Overall Data Format

The 7500 eleven-bit-plus-sign words per second in the data format include 25 data points from the low speed subsystem, 25 identification words for low speed data, 25 identifications and control words, and 7425 data points from the high speed subsystem.

In addition to the data received from the analog-to-digital converters, the Master Assembler receives the digital identification and control data and inserts them in the proper points in the data flow. This includes such information as the job run, station, test run numbers, test conditions read from switches at the test control stations (beginning or end of test, calibration, etc.), and time information read from the system clock (day, hour, minute, second, and tenth of second). Also, switches in Data Central permit data to be flagged as setup data, calibration data, or actual test-run data. These flags, introduced at the Master Assembler, serve as instructions to the computer for the subsequent manipulation of the data.

The extra-high-speed rate of 15,000 data points per second is handled according to a different scheme. One DCMH (100 channels) is assigned, when necessary, to this special use. Two multiplexers, two transmission lines, and two analog-to-digital converters operate alternately, each at 7500 cps. A double-sized assembler receives the data from the alternating converters and it is recorded on a 30,000 character-per-second tape transport.

From the Master Assembler, assembled data are switched to the bar graph displays, to the tape transports, and on-line to the computer, where they are used as determined by the test setup.

Computation

The computer subsystem performs as an on-line device; it is an integral part of the data collection system. Engineering information is accepted, processed, and output to printers, plotters, and other display devices, in real time, for the use of those monitoring the test specimen and facilities.

This subsystem can compare a large number of channel readings with preset upper and lower limits and give an alarm when a channel exceeds its limits. It selects the predetermined channels to be displayed by the real-time output stations, converts their readings to engineering units, and transmits the readings to the display units.

The computer subsystem consists of two CDC 160-A computers linked through a shared memory. One computer will normally be connected to the Master Assembler of the data system and perform the on-line functions described above. The second computer serves as a spare for the first, and also is available for the off-line analysis and output of data fed to it by any of the output media of the data system or stored in the joint memory. It can also be used as a completely separate computer for routine computing tasks.

The off-line functions include processing high speed data previously recorded on tape, processing telemetry data, preparing maintenance reports from data generated by the running-time subsystem, scheduling the test facilities, budget computation, and processing scientific data in support of research.

Data from the telemetry channels of a satellite are demodulated, formatted, digitized where required, and delivered by a ground station in Operations Center into a buffer register. The computer commands the buffer register to "dump" its contents in 12 parallel lines. The resulting word can be stored in the common central memory of the computer subsystem without going through or being controlled by either computer mainframe. When the telemetry data are in memory, they can be called up and manipulated by either computer and the results can be put out in any appropriate form.

CALIBRATION AND MAINTENANCE

Several types of calibration are provided: At each DCML, the first two of the fifty inputs are internal test points, either 0.0 or 8.00 millivolts. Each DCMH provides calibration inputs of +4, +2, 0, -2, and - 4 volts, as well as input voltages derived from each power supply in the DCMH. These are automatically sequenced and sampled by the DCMH at 3-record intervals.

A calibrate switch at the Data Central console initiates the following operation: A reference voltage is applied to each of the eighty conditioning modules in each DCMH; the voltage indicates the setting of each attenuator switch. The multiplexers are disconnected and a reference voltage is fed directly into each buffer amplifier. Each strain gage channel is calibrated by a 2-point linearity check (1/4 and 3/4 full scale).

Voltages at critical points within the system are automatically sampled and these data are processed by the computer, which compares the resulting digital reading with an expected reading stored in its memory. The pattern of the channels selected to carry these diagnostic inputs is designed so that a logical process permits the computer to isolate a malfunction by elimination, and to print out the location of the trouble or the instructions for eliminating it.

Clearly, it is impractical to perform this automatic diagnosis below a certain system level, and beneath this level a simplified manual diagnostic technique is used. This combination of computer and manual diagnosis is known as the PILE system (*P*rogrammable *I*dentification of *L*ogic *E*lements). In this data system, the cutoff is at the major device level; that is, the computer isolates the malfunction to a particular amplifier, analog-to-digital converter, or commutator, with the manual technique taking over for lower level diagnosis.

The manual technique is designed so that relatively inexperienced technicians may operate it satisfactorily. Each cabinet contains a booklet clearly locating the test points and showing the exact wave forms to be expected at each one. The sequence of testing is indicated by writing pseudo-logic equations for each logical circuit, in which each circuit element and function is identified by a short pronounceable word.

The functions schematically described above are actually performed by three complete sets of analog-to-digital converters, assemblers, and commutators located in Data Central. More than one of each type of instrument will be in use simultaneously only when such use is deliberately scheduled. Through convenient patch facilities, the equipment is easily interchangeable when a malfunctioning device must be replaced.

(Manuscript received February 4, 1964)

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